NASA LaRC/NIA Workshop on Transportation Network Topologies

Informal Introductory Remarks

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The existing transportation system, in general, and air transportation, in particular, is reaching the limits of its capacity in a number of ways. Mobility, throughput, customer satisfaction, safety, security, communications, fuel consumption and other ecological demands are some of the major problematic aspects of the current system that must be addressed in the increasingly complex and populous world.

Transportation systems, such as airports connected by routing via the National Airspace System (NAS), are networks of great practical interest, but our understanding of their dynamic behavior is limited. Current *ad hoc* analysis techniques of transportation systems are often static and incomplete. With some notable exceptions (e.g., the design of VLSI, pipelines, scheduling), the design of complex networks with respect to objectives of applied interest is at an embryonic stage. As with other systems, however, improvements in the transportation systems will rely on the existence of two basic components: analysis and design.

Recent developments in the study of complex systems and network theory, in particular, have led a number of researchers at NASA LaRC to begin preliminary investigations into the applicability of the latest developments in complex system theory to the analysis and design of alternative transportation architectures. We hope that the coming workshop will serve as a forum for exchanging ideas, starting collaborations, and initiating several lines of inquiry by examining the following questions (not an exhaustive list):

- What is the state of the art in modeling and design tools for current transportation systems?
- Because transportation systems are networks, clearly they should be examined with methods aimed at network analysis. What aspects of the network theory are applicable to the study of transportation systems and what aspects are non-existent or not sufficiently mature? Can we identify critical tools and methods, either existing or requiring development, for the analysis of realistic transportation networks?
- It is important to "map" the developments in network theory to transportation problems. What is the best or feasible way for developing such a mapping, in general, or a dictionary (a lexicon), in particular?
- What kind of a network should a transportation system be? For instance, scale-free networks have a number of attractive characteristics, such as high degree of connectivity (the "small world" property) and consequently a high degree of robustness with respect to some objectives, and the "scale-free" property. However, their structure also makes scale-free networks vulnerable to catastrophic failures. Assuming that we can design hybrid networks, what are the desirable properties of a transportation network?
- How much uncertainty can be tolerated in a transportation network? Or, in other words, how much controllability must a network have? When networks reach some degree of

complexity, they exhibit self-organizing or "emergent" behaviors. How can we account for such behavior? Does the need for controllability imply that we are necessarily limited to certain kinds of hybrid networks?

- Can we design networks for objectives of interest rather than for theoretical network objectives? Can we map theoretical network objectives to applied objectives? What is the design problem formulation (variables, objectives, constraints)?
- How do we estimate the time and effort required to develop methods and tools for realistic transportation network design in all its complexity? (See Bruce Holmes' slides for the description of the multitude of communicating layers in transportation systems.)
- Given that we will not be able to handle the analysis and design problem in all its complexity for a long time, what are the subproblems of most practical interest that we can address in the near future? Can we establish taxonomy of subproblems whose solutions will be of value and will advance the state of the art on the road to overall transportation system design?
- What are clear, simple cases for which we can compare various simple transportation topologies and which can be used for the development of methodologies?
- Whom should we try to interest in this line of research? What are the potential collaborations?
- What would be a fruitful agenda for a potential larger workshop 6-9 months from now?

In summary, we would like to examine the feasibility of applying network theory and potential alternatives to the analysis and design of transportation systems, identify state-of-the-art models and methods, and identify methods and tools that have yet to be developed. We would thus like to lay a foundation for a roadmap to developing methods and tools that will lead us to a clearer understanding and modeling of dynamic behavior of transportation systems, as well as to enabling their design.